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Spectral Properties of Clouds.
by K. S. Shifrin

1. It is the aim of the present paper to analyse theoretically the properties of clouds on the grounds of a detailed analysis of scattering and absorption of radiation by a separate cloud drop.

2. Cloud drops are large in relation to solar radiation. Effects of diffraction remain only in the region of coronas, rainbows and back scattering. As to other regions of the scattering angles, spectral peculiarities arise only due to variations of the liquid water refraction index.

We have carried out detailed computations of scattering pattern for λ, taking into account five beams of geometrical optics found in the range 0.35-1. 1μ, as well as for m, in the range 1,3200-13450 (six values, through Δ m=0.0050) [1].

Computations were made for both the two states of polarisation "S" and "P" and for the natural light.

It was found that the cloud drops can actually be considered to be white for all the scattering angles (except the range 60-95°) within 10% accuracy which is valid for the whole examined spectral region. In the range 60-95° spectral changes are rather significant and reach ±80% (in relation to the red line λ_c =0.656μ, m=1.3300).

3. Comparative analysis of the role of drops and vapour was made before investigating the transfer of longwave radiation. The effect depends on the relationship of temperature and water content. For the conditions of a typical example it was found that the attenuation of the blackbody radiation flux will be 80% due to drops and 20% due to vapour [2] in the case of passing through a cloud layer 10m.

4. Scattering and absorption of thermal radiation are of an essentially diffraction character. Detailed computations were made for a typical cloud drop of the radius a =6.265μ and for λ lying in the range 3-117μ [2,3,4].

Results of computations of attenuation coefficient K, scattering coefficient Kp, and absorption coefficient K_n, (in units of geometrical section πa^2 of a drop) are given in Table 1.

Table 1.

λ μ	K	K_p	K_n	K'_p
3	2.004	1.110	0.894	0.1276
3.4	2.4664	1.5412	0.9252	0.1348
4.5	2.646	2.146	0.500	0.1307
6	2.870	1.743	1.127	0.0467
7	3.299	2.595	0.704	0.0273
8	3.201	2.967	0.234	0.0425
9	2.4921	1.8626	0.6295	0.0505
10	1.4998	0.92485	0.5750	0.0136
11	1.233	0.4653	0.7677	0.00808
12	1.766	0.6321	1.134	0.0166
13	2.028	0.7922	1.236	0.0245
15	2.263	0.8869	1.376	0.0342
18	2.429	1.013	1.416	0.0457
52	0.9598	0.1449	0.8149	0.06033
63	0.7413	0.1041	0.6372	0.04697
83	0.5810	0.06685	0.5142	0.03094
100	0.2399	0.01895	0.2210	0.008924
117	0.1700	0.01039	0.1596	0.005025

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5. It is of interest that the absorption coefficient of the drop, K_n for $\lambda = 6\mu$ and $\lambda > 11\mu$ is greater than 1. It means that with this wavelength a drop radiates more intensively than the absolute blackbody radiation. It is certain that an optically "thin" layer of cloud drop will have the same property.

6. Table 1 allows us to appreciate the accuracy of "the layer of precipitated water" method which is generally used for the analysis of the radiation absorptio by a cloud or fog layer. The equivalence of a fog layer to a layer of precipitated water means that the absorption coefficient of the radiation in liquid water, α, is the value $\frac{3K_n}{4a}$

The comparison of these two values is given in Table 2.

Table 2.

$\lambda\mu$	α	$\frac{3K_n}{4a}$
3	7330	1070
6	2140	1349
9	700	753.6
12	2590	1357.6
18	2990	1695
52	1160	975.5
83	710	615.5
117	360	191.1

We can see that for $\lambda = 3\mu$ the values characterising absorption in the fog and in the corresponding layer of precipated water differ by 7 times.

7. Fluxes of thermal radiation in the layer of an arbitrary optical thickness were computed by the approximate Schwarzschild's method. It was found that it was necessary to know not only the whole scattering coefficient, K_p, but also the part of it scattered into the back hemisphere K'_p. A formula has been deduced [2] which allows K'_p to be computed, through the amplitudes of Mie's partial waves, avoiding the computation of scattering pattern or its successive integrating over the hemisphere. The results of computations for K'_p in the case of our cloud drop are given in the fifth column in Table 1.

8. Calculations show that whatever an incoming flux of radiation into the cloud may be, at some distance R^*, it transforms into a flux of blackbody radiation at the temperature of the examined level in the cloud.

The thickness of the radiation boundary layer R^* for various wavelengths appears to be different. It depends on the water content q, and the cloud temperature t. For example, when $q = 0.5 \frac{g}{m^3}$, $t = -8^\circ C$, then R^* for λ 4, 8, 14 μ will be 60, 165 and 35 m. respectively. Outside the radiation boundary layer, i.e. inside the cloud, a passive transfer of thermal radiation occurs and the value of radiation balance is zero.

This fact was corroborated by V. L. Gaevsky, who carried out the direct measuring of thermal radiation fluxes in the clouds Sc and Cu [5]

9. Spectral longwave albedo of the cloud has been computed. It was found that for a cloud optically infinite in its thickness the albedo has two maxima of 13% and 8% at 5 μ and 8 μ respectively. On the average, it is 2% over the whole spectrum.

10. It is certain that the value of radiation of a layer optically finite in its thickness does not exceed that of the blackbody radiation.

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11. An approximate method of estimating the spectral characteristics was developed for the drops of different sizes.

It is shown that the clouds and fogs spectra may be well described by a general formula of four parameters,

$$\psi(a) = A a^{\mu} e^{-\beta a^{\gamma}}$$

This formula agrees with both Hageman's data on drop distribution in the fogs near the ground [6] ($\mu = 8$, $\gamma = \frac{1}{2}$) and the Schuman's distribution in clouds ($\mu = 2$, $\gamma = 3$) and it is true in many other cases. With the help of this formula it is possible to compute the spectral properties of a cloud with any given microstructure determining the distribution parameters μ and γ by means of the known recipe.

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ON THE ROLE OF DIFFERENT FACTORS INFLUENCING THE EXTINCTION OF LIGHT IN THE EARTH'S ATMOSPHERE

By T. P. Toropova

Experimental investigations of the role of different factors in the extinction of the light in the earth's atmosphere are effective only in the case both of investigations of spectral transparency, and of principal factors affecting the passage of light through the atmosphere. Water vapour is one of these factors.

The present paper deals with the results of measurements of the spectral transparency in the region of 4100 Å up to 10100 Å and the results of spectroscopic determination of the water vapour content in the atmosphere.

These observations, as well as the observations of the Sun aureole, made with an aureole photometer of Academician Fesenkov's construction, allow us to judge the role of different factors in the extinction of the atmosphere.

1. Monochromatic coefficients of transparency have been determined by a routine long method of Bouger, with an accuracy of 1% from the spectrograms of the Sun, obtained with the help of a photoelectrical spectrophotometer. On the whole, the observations of transparency have been carried out over 50 days in 25-30 parts of the spectrum in the region of 4100 Å up to 10100 Å.

2. Determination of water vapour content in the atmosphere has been done by a spectroscopic method in the band, with a maximum absorption at the wavelength 0.94 μ. On the basis of aerological data, a calibration curve relating the depth of an absorption band to water vapour content in a centimetre of precipitable water has been plotted and made it possible to determine the water vapour content throughout the entire thickness of the atmosphere, with an accuracy of 4-5%. About 600 determinations of the water vapour content have been carried out over 102 days of observations.

On the basis of these data a seasonal variation of the water vapour content has been obtained and compared with a seasonal variation of absolute humidity at the earth's surface. To clear up the question of the possibility of determining the water vapour content throughout the entire thickness of the atmosphere, according to the measurements of the absolute humidity at the surface, the coefficient of a linear correlation has been computed between the absolute humidity q at the surface and the water vapour content w throughout the entire thickness of the atmosphere. For quite clear cloudless days the correlation coefficient has appeared to be 0.87 ± 0.03. A root mean square of the regression coefficient is 0.26 cm. of precipitable water. Thus, measuring the absolute humidity at the surface, one can determine the water vapour content throughout the entire thickness of the atmosphere with an average error equal to 0.25 cm. of precipitable water, i.e. with an average accuracy of 10 up to 50% since the contents of the water vapour over a period of observations varied from 2.52 to 0.20 cm. of precipitable water.

In order to clear up whether it is possible to determine the water vapour content in the atmosphere without plotting an experimental calibration curve, a test of applicability limits of logarithmic law and a root mean law to the ρ band has been made. The coefficients of linear correlation have been computed between the water vapour content in the atmosphere and the intensity of the Sun aureole, measured in four parts of the spectrum for the wavelengths of 445, 546, 636 and 900 $m\mu$. Their values have appeared to be respectively 0.71 ± 0.05; 0.68 ± 0.05; 0.68 ± 0.05 and 0.69 ± 0.04. These figures are evidence of the great role of liquid aerosols in the formation of the Sun aureoles. On the other hand, it has been shown that in some cases the formation of the Sun aureole is due to particles

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of dust. Large correlation coefficients between water vapour content and the intensity of the Sun aureole speak for the relation between the contents of water vapour determined spectroscopically and that of liquid water as the aureoles are due to the scattering by large particles.

3. The control of the stability of optical properties of the atmosphere has been done by means of the method of Piaskovskaya-Fesenkova from the observations of the Sun aureoles with the help of an aureole photometer.

4. An example of a number of consequent days with an equal water vapour content, an equal respective humidity at the surface over a period of observations, and strongly changing transparency of the atmosphere shows that dry aerosols, in certain cases, greatly influence the passage of light throughout the earth's atmosphere.

5. A question of separating the molecular scattering, the extinction due to ozone and to water vapour from the general extinction of the light in the atmosphere in the observed region has been considered in this paper. The dependence of residual extinction upon the wavelength obtained after the subtraction of the indicated components from the entire thickness has been considered. Three types of dependence of aerosol extinction upon the wavelength have been found; (i) a neutral dependence, (ii) a monotonous increase of the optical thickness with a wavelength decrease, (iii) the dependence is expressed by a curve with a maximum. The maximum position is different for different days and varies from 460 up to 520 $m\mu$. The estimation of each component in the extinction has been made according to the mean data obtained before and after noon.

6. In conclusion, the question of applicability of the theory of molecular scattering to the earth's atmosphere has been investigated. It has been shown that if one selects absolutely clear, optically stable days after rain falls when the greater part of the pollution is washed out, and subtracts the extinction due to the water vapour, the atmosphere becomes very similar to the Rayleigh atmosphere. Loschmidt number determined from the spectral transparency on such days is different from the exact laboratory data only in the limits of an error.

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ON THE STUDY OF GEOGRAPHICAL DISTRIBUTION OF THE INDICES OF THE RADIATOR REGIME

By M.I. Budyko dir MGO Leningrad

Two main methods are used to study the geographical distribution of the indices of the radiation regime. The first of them is connected with the direct generalization of the data of actinometric observations. This method is comparatively seldom used to make the maps of mean values of the indices of the radiation regime, because more or less extended actinometric observations have been made at a comparatively small number of locations.

In this connexion, the other method is used more often for the compilation of maps of the indices of the radiation regime, which is based on the application of various computation methods of determining the components of the radiation balance.

This method was particularly used in some earlier studies carried out by the staff of the Main Geophysical Observatory, in which the maps of the total radiation, albedo, radiation balance of the earth's surface and of some other indices of the radiation regime have been compiled (1947-1955).

In the recent time the number of the available data of actinometric observations has been enlarged considerably due to the International Geophysical Year. This fact allows us to check the calculations made earlier and to evaluate the accuracy of the available maps of the indices of the radiation regime.

Now we have increased possibilities of applying the observational data directly to the compilation of new maps and to the development of methods of calculating the indices of the radiation regime.

In the recent studies carried out at the Main Geophysical Observatory the data of new actinometric observations have been used to perfect the methods of determining the short-wave solar radiation, long-wave effective radiation and the albedo of the earth's surface. The application of these methods has made it possible to compile more accurate maps of the radiation balance of the earth's surface.

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The radiation balance of slopes

By K. Ya. Kondrat'ev and M.P. Monolova

1. The need to investigate the radiation balance of slopes in the solution of many important practical problems. Recent data on different components of slopes, radiation balance.

2. Theoretical calculations and experimental measurements of radiation balance components for slopes situated near a flat horizontal surface. The determination of relative values of the radiation balance components (with respect to the components for the horizontal surface) as the most common characteristic of the radiation balance of slopes.

3. Calculations and direct pyranometric measurement of scattered and reflected radiation on slopes. Calculation of the angular nonisotropy of scattered and reflected radiation for a cloudless sky. The appropriateness of the "isotropic" approximation in calculation of scattered and reflected radiation for an overcast sky.

4. Qualitative correspondence of the results of the determination of global radiation on different slopes for a cloudless sky and a partly clouded one. The importance of non-isotropy of scattered radiation in the case of determining global radiation on slopes for low angular altitudes of the sun.

5. The plotting of the results of measurements of global radiation on slopes and the determination of relative values of global radiation for different slopes, and for solar altitudes from 20° to 70°, by means of the graphs.

6. Daily variation of global and scattered radiation for slopes with slope angles of 5, 10, 15, 20, 30, 50, 70, 90°, directed to the cardinal points in the case of a cloudless sky.

7. Relative daily amounts of global and scattered radiation for different slopes. The possibility of determining the daily amounts of global radiation on slopes by means of the "isotropic" approximation.

8. Measurement and calculation of the effective radiation of differently directed slopes. The insignificant dependence of relative effective radiation of slopes on the amount of water vapour in a vertical column of the atmosphere. The independence of the effective radiation of slopes with respect to azimuthal orientation. Graphical determination of relative values of the effective radiation of slopes.

9. Measurement of the radiation balance of slopes by ventilated balancemeter. The dependence of the relative slopes, radiation balance on the angle and azimuth of the slopes. The zone of negative radiation balance on a summer day for slopes in the direction opposite to the sun at low altitudes of the sun. The calculation of the radiation balance of slopes by means of graphs.

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RADIATIVE PROCESSES IN STRATIFIED CLOUDS

By E.M. FEIGELSON

Different aspects of the problem of a radiative energy transfer in stratified clouds have been investigated theoretically. Exact equations of transfer have been used as the principal tool. Their approximate solutions have been obtained in some particular cases.

1. The propagation of light within a cloud with regard to the scattering by water drops has been considered (1). Analytical expressions for the intensity of scattered light emerging through the cloud boundaries and its distribution in different directions have been obtained in a rough approximation.

2. The spectral fluxes of longwave radiation and their dependence upon the depth in a cloud have been calculated. It has been shown that only near the cloud boundaries are the net fluxes essentially different from zero.

3. The spectral and integral radiation absorption of solar radiation in clouds has been investigated (2). The amount of absorbed solar energy received by the cloud at each level has been evaluated. An indication is made of the region close to the upper boundary of the cloud, where most of the infrared solar energy is absorbed.

4. The vertical distribution of temperature in a cloudy atmosphere has been calculated. The atmosphere is supposed to satisfy the condition of radiative equilibrium (3). As a result of the calculations, the temperature at the upper level has been found out to be very low.

5. The processes of temperature change due to radiation transfer and accompanying water transformations have been considered. A qualitative investigation of the solutions of the latter problem and a calculation of the simplest cases have shown that:-

(a) the upper part of the cloud is intensively cooling down, especially at night due to the longwave radiation; while the adjacent layer above the cloud is cooling down very slowly. As a result of this a sharp temperature inversion appears.

(b) cooling does not extend deep into the cloud, and the thickness of the inversion layer is small.

(c) the maximum cooling is taking place at the upper boundary of the cloud. The physical parameters which determine the value of the maximum cooling have been found.

(d) the bigger the optical thickness of the cloud the narrower the layer at the boundary in which the cooling is concentrated.

6. Comparison with observation shows that the theory developed describes well enough the changes of temperature in the uppermost part of the cloud. The extension of cooling throughout the cloud as obtained from our calculations is not in good agreement with that measured. Therefore, a radiative model with allowance for turbulent mixing with a constant coefficient of exchange has been considered. The turbulent mixing essentially diminishes the effect of a radiative cooling at the upper boundary and at the same time causes a deeper extension of cooling into the cloud.

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ON SOME POSSIBILITIES OF EXPERIMENTAL DETERMINATION OF THE SPECTRUM OF TRUE ABSORPTION BY CLOUDS AND FOGS

By G.V. ROSENBERG

1. The spectrum of true absorption of a dispersed phase is essentially different from that of bulk matter and is dependent upon the size of the drops. Theoretical evaluations are difficult and as yet have not been carried out. This fact serves as an obstacle in the study of radiative processes in clouds and fogs. Therefore, determinations of the spectrum of true absorption are needed for naturally occurring drop-size distributions.

2. True absorption in a scattering medium is masked by the scattering, which is also dependent upon wave-length. Because of this the determination of true absorption may be possible only after considering the effects of multiple scattering, i.e. by solving the problem of radiative transfer. In principle, this solution must be done with regard to the effects of polarization of the radiation and for an arbitrary (unknown) matrix of scattering. This is possible in an analytical form only approximately and under some specific boundary conditions.

3. One of the above mentioned cases is the light regime in the interior of a thick cloud layer illuminated by the sun. In this case a simple relation exists between true absorption and some measured parameters of the light regime.

4. The second case is the reflection power of an infinitely thick layer with either very strong or very small absorption, when some simple relations between reflection power and specific absorption can be derived, involving a few experimental parameters. However, determination of these parameters requires additional experiments (for example, artificial "colouring" of a cloud) or the assumption of a small dependence of these parameters upon the wave length - which assumption requires special investigation.

5. In the case of absorption which is neither very strong nor very small some rough approximate methods can be used, which are applied in the spectroscopy of powders and based on measurements of the reflection and transparency spectra of layers of different thickness. Application of these methods also requires additional experiments for determining auxiliary parameters.

6. The degrees of reliability of the above mentioned methods and possible ways of their realization under different conditions is discussed.

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SOME REGULARITIES IN THE SCATTERING OF LIGHT BY THE EARTH'S ATMOSPHERE

By E.V. PYASKOVSKAYA-FESENKOVA

1. During 11 years in 12 different localities the author investigated the brightness of the cloudless day sky under various climatic, meteorological and synoptic conditions, at different heights above the sea level ranging from 3 to 3140 meters. The observations were made with a visual photometer of special construction and with a photoelectric photometer designed to measure the illumination on a standard surface normally placed from the circumsolar sky and also from the sun.

2. If the angle of scattering is equal nearly to 60° then there is a quite definite relation between the coefficient of transparency or the optical thickness of the atmosphere and the coefficient of scattering of light $\mu(\theta)$. This relation is lacking for small angles of scattering.

3. It is shown that an atmosphere with Rayleigh indicatrix of scattering in the interval of the angles $60^\circ \leqslant \theta \leqslant 90^\circ$ and an atmosphere with sperical indicatrix near $\theta = 57^\circ$ behave like the real atmosphere if only the coefficient of transparency is the same.

4. It is shown that there is no particular indicatrix of scattering appropriate preferentially to some definite locality, for instance to mountains or to plains. But some definite $f(\theta)$ is more or less recurrent according to local conditions.

5. The brightness of the day sky in one locality can be determined from observations made in another locality if corresponding atmospheric trasparencies are known.

6. The brightness of circumsolar sky varies during the day. The maximum of this brightness corresponds to the moment when the atmospheric mass becomes just equal to the inverse of the optical thickness of the atmosphere in the direction of the sun. This relation allows the determination of the coefficient of atmospheric transparency with sufficient exactness.

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Messung der Sonnenstrahlung

n. F. Volz

Mit dem neuen leicht transportablen Sonnenphotometer kann die Blau- und Rotstrahlung der Sonne (λ 0,44 und 0,64 μ) sehr schnell bestimmt werden. Als Empfänger dient ein Selen-Photoelement, der Photostrom wird mit einem Mikroamperemeter gemessen. Um Trübungsbestimmungen mittels eines Diagramms zu erleichtern, kann die relative Schichtdicke der Atmosphäre an einer Skala direkt abgelesen werden.

1. Aufbau des Sonnenphotometers

Das in einem Holzkästchen eingebaute Gerät besteht aus einem Tubus mit Linse, Filtern, Photoelement und Diopter sowie einem Mikroamperemeter und einer Libelle. Der Tubus wird mittels eines Handrades und des Diopters auf die Sonne eingestellt; bei horizontiertem Kästchen (Libelle) kann dann an der nichtlinearen Skala des Handrades die relative Schichtdicke M der Atmosphäre abgelesen werden.

Die Sonnenstrahlung tritt durch eine Linse von 45 mm Brennweite in den Tubus ein. Eine mit Mattglas hinterlegte Lochblende im Brennpunkt der Linse begrenzt den Öffnungswinkel des Instruments auf ca 1° (bei Aktinometern meist 5°) und bewirkt diffuse Bestrahlung des am Ende des Tubus angebrachten Photoelements. Hinter der Lochblende befindet sich ein Schieber mit den Farbfiltern (Schieberstellungen: Dunkel, Blau, Rot). Bei geringer Strahlungsintensität kann die Empfindlichkeit des Instruments durch Vergrößerung der Linsenöffnung auf das 3 bis 4-fache vergrößert werden.

2. Photoelement, Mikroamperemeter und Filter

Der durch die Belichtung des Selen-Photoelements hervorgerufene Photostrom wird an einem Mikroamperemeter mit 60 bis 100 μA Vollausschlag und ca 800 Ohm Widerstand abgelesen. Unter diesen Messbedingungen gilt für die einzeln untersuchten und ausgewählten Photoelemente:

a) die Kurzzeitermüdung beträgt weniger als 1,5% bei 5 Sec. Bestrahlungsdauer
b) die Temperaturabhängigkeit des Photostroms beträgt im allgemeinen höchstens 0,5% pro 10°C;
c) Belichtung und Photostrom sind streng proportional;
d) die Empfindlichkeitsänderung der künstlich gealterten Photoelemente beträgt nach bisherigen Erfahrungen höchstens wenige Prozent pro Jahr.

Als Blaufilter dient Schott FG 12, als Rotfilter eine feuchteunempfindliche Farbfolie. Die Durchlässigkeit beider Filter ändert sich nur um -0,3 bzw.-0,5% pro 10° Temperaturzunahme. Aus der Spektralempfindlichkeit der Photoelemente, der Durchlässigkeit der Filter und dem Sonnenspektrum ergeben sich die effektiven Wellenlängen $\lambda_B=0{,}44$ und $\lambda_R=0{,}64$. Die Spektralbereiche sind so eng, daß die Messungen hinsichtlich der Extinktionsbestimmungen gut monochromatisch sind.

Wegen der kleinen Temperaturkoeffizienten von Photoelement und Filter ist es normalerweise nicht nötig, bei der Auswertung der Messungen die Temperatur des Instrumentes zu berücksichtigen.

3. Eichung und Auswertung

Die Eichung des Gerätes ist leicht durchzuführen, wenn Tagesgänge der Sonnenstrahlung an Tagen mit gleichmäßiger Trübung gemessen wurden.

Zur raschen Bestimmung der Trübung der Luft durch Dunst und Staub aus den Messwerten wird dem Sonnenphotometer ein Diagramm beigegeben. Die Auswertung unter Berücksichtigung der Extinktion durch Luft und Ozon ergibt den "Trübungskoeffizienten B" für $\lambda = 0{,}5\mu$ und den Wellenlängenexponenten α der Dunstextinktion. Ersterer ist ein Maß für den Aerosolgehalt der Luft, letzerer für die Größenverteilung des Aerosols.

Falls nur die Messung der visuellen Bestrahlungsstärke durch die Sonne beabsichtigt wird, ist es vorteilhafter, das Sonnenphotometer nur mit einem Grünfilter auszustatten, so daß die Spektralempfindlichkeit weitgehend mit der Augenempfindlichkeit übereinstimmt. Doch ist auch dann die Bestimmung des Trübungskoeffizienten mit einem vereinfachten Diagramm möglich.